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► To cite this version:

D. Raabe, G. Gottstein. Rolling textures of a Cu-20% Nb composite. Journal de Physique IV Proceedings, 1993, 03 (C7), pp.C7-1727-C7-1730. 10.1051/jp4:19937271 . jpa-00251912

HAL Id: jpa-00251912

<https://hal.science/jpa-00251912>

Submitted on 1 Jan 1993

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Rolling textures of a Cu-20% Nb composite

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ABSTRACT

Heavily rolled in-situ MMCs of Cu-20 vol% Nb have been investigated by means of quantitative texture analysis mainly for three reasons. First, the crystallographic texture can be very sensitive to the deformation process. Second, the orientation distribution affects the strength of the material in terms of the Taylor factor. Third, the influence of a massive second phase on texture development is of general interest for texture evolution of in-situ processed composites. The textures of both phases in the MMC were compared to those of single phase Cu and Nb, respectively. The results were interpreted by means of Relaxed Constraints Taylor Theory.

INTRODUCTION AND EXPERIMENTAL

Cu and Nb have neglectable mutual solubility. Ribbon reinforced in-situ MMCs can thus be processed by large degrees of deformation. The deformed Cu-20 vol% Nb composite reveals a tensile strength which exceeds the value predicted by the rule of mixtures. Various models have been proposed to explain the observed strength anomaly. The barrier model by Spitzig et al. (1) attributes the strength to the difficulty of propagating plastic flow through the fcc-bcc interfaces while the group of Courtney et al (2) interprets the strength in terms of geometrically necessary dislocations owing to the incompatibility of plastic deformation of the bcc and fcc phase. Both models are able to describe the increase of strength by assumption of fitting parameters, although the actual strengthening processes are still unknown.

The cast Cu-20 vol% Nb composite was rolled to $\epsilon=88\%$, 96%, 97%, 99% and 99.5% deformation. Incomplete X-ray pole figures were measured from 5° to 85° in the back reflection mode. From a set of four pole figures ($\{111\}$, $\{200\}$, $\{220\}$, $\{311\}$ for Cu and $\{110\}$, $\{200\}$, $\{112\}$, $\{103\}$ for Nb) the orientation distribution function (ODF) was calculated using the series expansion method (3). For correction of "ghost" errors the calculated ODFs were approximated by model ODFs (4).

RESULTS AND DISCUSSION

The rolling texture evolution of Cu in the composite (Fig.1) is very similar to the texture development of pure Cu (Fig. 2) (5), except for two details. At very large deformation ($\epsilon=99.5\%$) the C orientation $\{112\}<111>$ decreases from 16 vol% to 10 vol%, whereas the background rises from 20 vol% to 26

vol%. In pure Cu the C component typically decreases at very large deformation, while its twin of first generation increases and the background decreases (Fig.2a). The increase of the twin is however not observed in the composite. Moreover, small amounts of $\{001\}<100>$, which is a recrystallization component in copper (6) appear, although not systematically with increasing deformation (Fig.1b). We interpret this phenomenon as a result of dynamic recrystallization. In case of static recrystallization the cube or the $\{025\}<100>$ orientation should increase continuously with increasing deformation (Fig.2b). This is at variance with the measurements. Since $\{001\}<100>$ is unstable upon rolling, it rotates away with increasing degree of deformation, so that no steady increase of $\{001\}<100>$ can take place during deformation. The decrease of the C orientation (Fig.1a), combined with the increase of the background at $\epsilon=99.5\%$ can then be attributed to the formation of cube nuclei from the C orientation, because from static recrystallization experiments it is known that the cube orientation nucleates preferentially in the C component (6). The newly formed orientations with volume fractions below 2-3% enrich the background only. This interpretation would also explain the low dislocation density in the Cu phase of the composite (1).

The texture of the Nb phase in the composite is characterized by a sharp bcc- α -fibre (Fig.3a) and the absence of $\{111\}<112>$ on the γ -fibre (Fig.3b). This can be understood in terms of "Relaxed Constraints Taylor Theory" (7). Texture simulations according to Taylor are based on the description of macroscopic deformation by means of crystallographic slip. The macroscopic deformation is characterized by the displacement gradient tensor. Its symmetric part represents the strain tensor, while the antisymmetric part describes the resulting rigid body rotation. The macroscopic deformation during rolling consists of elongation in rolling direction and thickness reduction parallel to the sheet plane normal, but no shears are involved. The relaxed constraints Taylor theory assumes also shear strains to occur microscopically. A relaxation of the strain component ϵ_{13} corresponds to a shear in longitudinal direction, while ϵ_{23} denotes transverse shear. Allowing for these shears locally leads to distinct changes in the rigid body rotation and thus in the texture development when compared to the predictions by full constraints Taylor theory (8). The Nb texture in the composite can be modelled by Taylor theory with relaxed ϵ_{23} constraints (Figs.3b,4c). For pure Nb the ϵ_{13} and the ϵ_{23} constraints both can be relaxed because of microstructure evolution during deformation ("pancake-model"). The simulated texture shown in Fig.4b exhibits a strong $\{111\}<112>$ component and thus corresponds to the measurements of pure Nb (Fig.5b). In single phase material a significant shear ϵ_{23} cannot be allowed without generating severe incompatibility problems between adjacent grains. In a composite, however, the Nb ribbons are embedded in a softer, maybe even recrystallized Cu matrix, which mitigates the incompatibility created by a shear ϵ_{23} in the Nb (Fig.6). Allowing for $\epsilon_{23} \neq 0$ during rolling suppresses the development of the $\{111\}<112>$ component (Fig.4c) in agreement with the Nb texture in the composite (Fig.3b). This means that in the composite the constraints for Nb become anisotropic, allowing a stronger ϵ_{23} shear of Nb into the Cu phase but hinders its ϵ_{13} shear.

CONCLUSIONS

The texture of a heavily cold rolled Cu-20 vol% Nb composite was measured. The results were compared to texture simulations according to Taylor theory and to the rolling textures of single phase polycrystalline Cu and Nb, respectively. For $\epsilon < 99\%$ the orientation distribution of Cu in the composite and of single phase Cu developed very similar but at $\epsilon \geq 99\%$ significant differences were observed. The changes are attributed to dynamic recrystallization in the Cu phase of the composite. The textures of pure Nb and of Nb in the composite develop differently such that the evolution of $\{111\}<112>$ is suppressed in the composite. This behaviour can be modelled by Taylor theory with relaxed ϵ_{23} and enforced ϵ_{13} constraints. We interpret this transverse shear as the consequence of the embedding of hard Nb ribbons in a soft Cu matrix.

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FIGURES

Fig. 1
Cu in the composite.
(a) τ -fibre
(b) Cube rotation
about rolling direction.

Fig. 2
Single phase Cu.
(a) τ -fibre
(b) Cube rotation
about rolling direction.

Fig. 3
Nb in the composite,
(a) α_{bcc} -fibre, (b) γ -fibre

Fig. 4
Simulated textures according to relaxed constraints Taylor theory, with relaxation of
(a) ϵ_{13} (b) ϵ_{13} and ϵ_{23} (c) ϵ_{23}

Fig. 5
Single phase Nb.
(a) α -fibre
(b) γ -fibre

Fig. 6
Illustration for transverse shear of the Nb phase into the softer Cu phase.